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Biochar for sustainable soil, agriculture and energy systems

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What is Biochar?

Biochar is a black, carbon-rich, material produced by thermally treating biomass materials in zero- or limited-oxygen conditions using a process called pyrolysis. When applied to land, biochar is not only a carbon sink, but can act as a soil improver by increasing the water and nutrient-holding capacity of the soil. It may also be effective in reducing greenhouse gas emissions from the soil. With the correct calibration, therefore, biochar application could offer considerable benefits in terms of mitigating climate change, improving food security and reducing reliance on chemical fertilisers, all of which could have considerable environmental and economic advantage.

Biochar can most easily be described as finely ground charcoal. However, that is not the whole story and there are a number of key factors which make biochar distinctly different from the traditional charcoal we use for our barbeques:

- Biochar is applied back onto the land rather than being burned;
- Biochar is produced and used in the form of small granules or a powder rather than big lumps;
- Biochar can be produced from a wide range of different materials, not just wood.

Why apply biochar to land?

In order to grow, plants sequester CO_2 from the atmosphere and convert the carbon into fixed biochemical structures that make up the building blocks of the plant biomass. This is the reason why dedicated energy crops such as *Miscanthus* are often referred to as carbon-neutral; the processes of harvesting and then burning

plant biomass to provide heat and power release roughly the same amount of CO_2 that is sequestered from the atmosphere during growth. Even when that biomass is not utilised but left to decompose or used for compost, the same principles apply because, during the process of natural decomposition, the carbon contained within the biomass will eventually be released back into the atmosphere, albeit at a much slower rate than when the material is burned.

When biomass is converted to char by heating in anaerobic conditions, the resulting product is the black, carbon-rich substance we are all familiar with as charcoal. However, the pyrolysis method of thermally treating the biomass transforms the carbon into a more stable physical structure, meaning that the rate at which it will naturally degrade and release its carbon as CO_2 back into the atmosphere is much slower. Therefore, providing that the biomass is charred (pyrolysed) in a sustainable manner, when it is added back to the land it constitutes a 'carbon sink', enabling a simple method of carbon capture and storage.

Is it all just about climate change mitigation?

Whilst mitigating climate change is an integral aspect of biochar production and application, it also has several other important benefits for soil health and productivity, especially in terms of improving the sustainability of the agricultural systems we rely on for food production and, increasingly, fuel production in a changing environmental and socio-economic landscape.

As mentioned above, soils rich in carbon have enhanced physical and chemical properties for supporting plant growth. Over time, however, as a result of both natural processes and cultivation, these soil carbon pools become depleted. Biochar addition therefore represents one way

of sustaining soil carbon pools and the productivity on which our agricultural systems depend. However, more productive soils also lead to greater production of biomass, which, in turn, means a greater amount of CO₂ being sequestered from the atmosphere. Hence, sustainable agricultural production, soil carbon management and climate change mitigation are inextricably linked.

Adding biochar to the soil creates a char layer which can be considered to act in a manner similar to a domestic charcoal water filter. It adsorbs certain chemicals or nutrients and prevents them leaching through to deeper levels and watercourses. Biochar application may also prevent nutrients leaching from soils, thereby improving their availability for use by plants, potentially reducing levels of nutrients percolating through soils, which may have a polluting effect to water courses if allowed to accumulate.

What is IBERS' role in all this?

In order for the biochar concept to become a reality, it is essential to be able to assess the whole lifecycle of biochar production and utilisation. Due to the multi-disciplinary nature of IBERS, we are able to investigate both the production and application of biochar and take a holistic approach in our research.

Biochar production

Biochar production as a means of efficiently sequestering and storing carbon is only sustainable if it does not release more CO₂ and other greenhouse gases than it effectively captures. In traditional methods of charcoal production, 50-70% of the biomass is lost through the chimney as gaseous and particulate emissions, and much of the heat produced during the process is also wasted.

Modern char production using pyrolysis facilities may overcome these limitations by capturing the residual heat and gaseous by-products using combined heat and power (CHP) systems. In combination with a biorefinery

approach, this will generate not only biochar but an additional range of useful co-products such as bio-oil and syngas, as well as heat which can be captured and used to power secondary processes. In order to investigate these options, IBERS has received funding from the Welsh Government's 'Academic Expertise for Business' (A4B) programme to perform research into the production and application of biochar through IBERS' 'Biochar for Business and the Environment' (ABATE) project. Through this project, IBERS has been working with the Cardiff-based engineering company Sustainable Energy Ltd to design and commission a state-of-the-art experimental biochar production facility, which can produce biochar in 100-300 kg quantities from a diverse range of feedstocks such as grasses and organic wastes, as well as wood (Fig. 1).

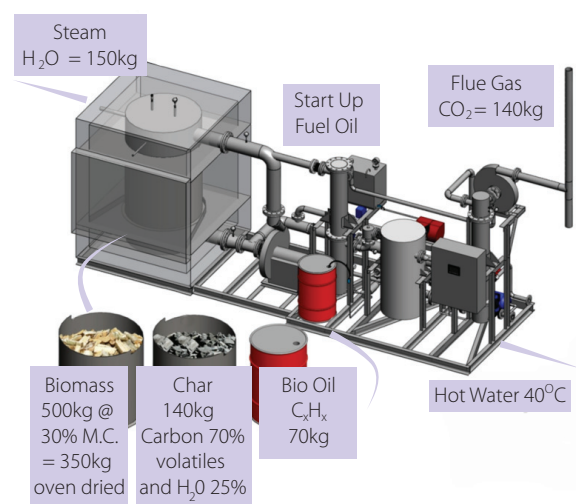


Figure 1. IBERS biochar production facility.

This biochar facility will be used to trial a wide variety of fresh and waste feedstocks that presently represent under-utilised resources. The potential for adding value to the process will be investigated by converting the input materials into both biochar and bio-oil and examining how the process can be optimised to enhance both conversion efficiency and product quality. Trials are being performed in tandem to assess the environmental benefit of biochar as a carbon sink and soil conditioner through a series of pot and field trials looking at the effects that biochar addition may have on practical soil and plant productivity under different conditions.

Biochar utilisation

Much of the existing evidence for the benefits of biochar has been obtained from research in tropical regions. In contrast, there is little current data demonstrating the benefit of biochar addition to temperate soils. In the CHARBON project, funded by the UK Energy Research Centre (UKERC) and the National Endowment for Science, Technology and Arts (NESTA), the growth of perennial ryegrass (*Lolium perenne*) has been used to test the effects of biochar addition to different soil types, with and without adequate water supply, in a series of pot trials at IBERS.

Perennial ryegrass (*Lolium perenne*) was grown with and without 5% char in different soils for 6 weeks. These growth studies demonstrated that the effect of biochar on the growth of *L. perenne* was dependent on soil type. The addition of biochar made little difference to the final biomass yield of *L. perenne* grown in compost or sandy soils, but biochar amendment to clay soils had a positive effect on the yield of *L. perenne*, resulting in increased tillering and almost doubled yield, as shown in **Fig. 2**.



Figure 2. Perennial ryegrass plants grown in clay soil with (Right) and without (Left) biochar.

The major cause for the observed yield enhancement was determined to be through a 'liming' effect as the biochar contains substantial concentrations of alkalis and alkaline earth metals. The biochar used for the pot treatments had a pH of 9, well above the neutral pH of 7, and was found to have raised the pH of the clay soils from 5 to 6.5. Since pH sustains the availability of essential nutrients, it is a major consideration in crop management and therefore a key consideration when assessing the efficacy of biochar as a soil amendment. In addition, a decrease in soil bulk density through biochar addition was also observed to be a contributing factor to the improved grass yields obtained from the clay soils.

What next?

Future biochar research at IBERS will focus on three main areas:

1. biochar production and char quality,
2. carbon mitigation potential of biochar,
3. the effects of biochar on soil fertility and plant productivity.

These studies will be integrated to determine the problems and opportunities presented by biochar production and utilisation both in terms of improving the sustainability of agricultural systems and for the potential to operate as part of an integrated biorefinery process for fuels and other commercially-valuable products. In this way, the project will provide the data required to enable evidence-based policy for this new application of an ancient technology.